Chinese Seal Recognition Using Hybrid Electro-Optical Filter

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ABSTRACT

We present a new technique for Chinese seal recognition using constrained energy minimization joint transform correlator (CEMJTC). Either optical or digital correlation is one of the most powerful operations for detecting the presence/absence of the seal image. The CEMJTC is proposed to improve the discrimination capability for shift-invariance and rotational-invariant seal recognition. By minimizing the average correlation energy with respect to all training seal images, while constraining the correlation peak value to a constant, a filter function is constructed. The main emphasis is to design a filter for good discriminate ability. Numerical results are presented to demonstrate the improvements. Furthermore, experimental results show the sharp correlation output profile when the seal image is correct, otherwise the correlation peak will be obviously reduced. The new technique for seal recognition shows a significant increase in high speed and detection ability.

Key words: CEMJTC; Pattern recognition; Optical correlation; Optical filter

1. INTRODUCTION

For the purpose of person identification, seal are used in Chinese society in stead of signatures on many types of articles such as paintings, documents, checks, receipts, money withdrawing lists, etc. A problem encountered in seal pattern recognition is the nearly infinite variation of seal imprints even if the imprints are all produced from the same seal, such as nonuniformly stained paints, different stroke widths, rotation, spot noises, a broken edge, blurred parts, double setting, etc. The variation results from many factors. For example, the force a person uses in setting a seal on paper is almost always different and often nonuniform or the seal may be stained on the seal head [1,2]. In contrast to other methods, seal imprint recognition can be achieved with the optical correlator, for which two widely used schemes have been the VanderLugt optical correlator [3,4] and the joint transform correlator (JTC) [5]. Since its introduction by Vanderlugt, optical correlation has been one of the most effective methods for optical pattern recognition [6,7]. Optical recognition methods based on the Fourier transform, such as the Vanderlugt correlator, or the joint transform correlator offer advantages such as parallel

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processing and large-volume databases [8]. Since the optical information processing system works at the speed of light and is a parallel process, it is a good for image recognition system [9]. During the past decade, optical signal processing has been used in a wide variety of applications, e.g., optical pattern recognition, image subtraction for machine vision, and optical computing. Although optical processing relies on general holographic filtering techniques, the concept of programmability in signal processing will be introduced [10]. This is primarily due to the advance in sophisticated spatial light modulators and photorefractive crystals that allow us to construct various types of near real-time hybrid optical information system [11,12].

A 2D input signal (i.e., an image) is processing in correlator, the description for the correlator is representatively (but not always) given in the frequency domain. Correlation can be implemented optically by the frequency plane correlator. The specialized filter suggests a system that passes certain frequency components and attenuates others. Optical correlation has been one of the most powerful operations for detecting the presence of a target in noise and clutter [13]. The correlation operation is attractive because of its shift-invariance, i.e., the output correlation distribution shifts directly proportional to the moving distance of the input target. As a result, the output correlator can not only detect the presence or not of the target image, but it can also track these images as they shift in the input plane, e.g., targets in different position [14,15]. The optical correlator at the speed of light makes it more attractive than electronic version for the pattern recognition. But, obviously, a purely optical processor has some drawbacks, which make certain tasks difficult or impossible to implement. The first is that an optical system is difficult to program as general-purpose electronic computers. Although an optical system can be designed to perform specific tasks, it cannot be used where more adaptability is required. A second drawback is that optical systems by themselves can not be used to make decisions as some electronic counter parts can [16,17]. To overcome the problem, optical system and electronic system can cooperate together. For instance, controllability and programmability are the advantage of the digital computer. Therefore we introduce an optical pattern recognition technique with assisting of the electronic computer. The CEMJTC setup offers clear advantages in practical implementations with respect to a VanderLugt correlator using a frequency domain MACE filter, where position match between filter and transform is critical to obtain a good correlation signal. The proposed system has the ability to recognize seal imprints regardless of the orientation and blurring.

2. Theoretical analysis

The implementation of hybrid optical setup is to use a conventional optical configuration, as shown in Fig. 1.

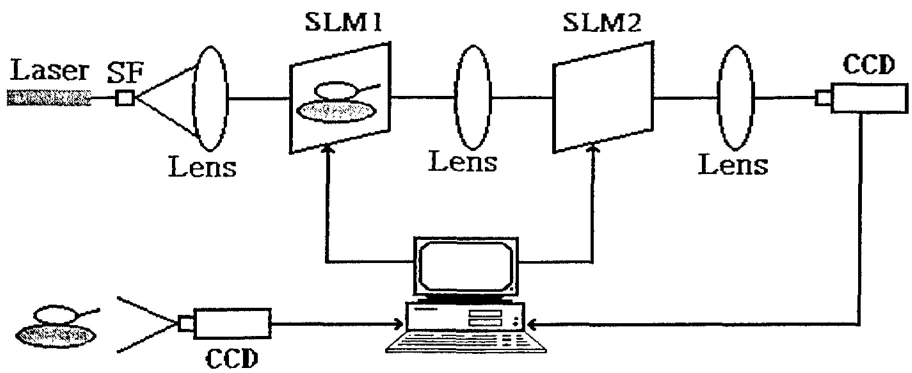

Fig. 1 VanderLugt optical configuration

Spatial light modulators (SLM1) contains input image pattern in the input plane, and the Fourier transform of the reference pattern is generated with the SLM2, through which cross-correlation (convolution) between the input object and the reference pattern can be detected by a charge coupled device (CCD) array detector. The detected signal can be fed back to the computer for display and for decision-making. That is, we can appropriately control the hybrid signal optical processor by a computer. An analog system diagram of the optical architecture appears in Fig. 3. The corresponded optical signal processor, is depicted in Fig. 4.

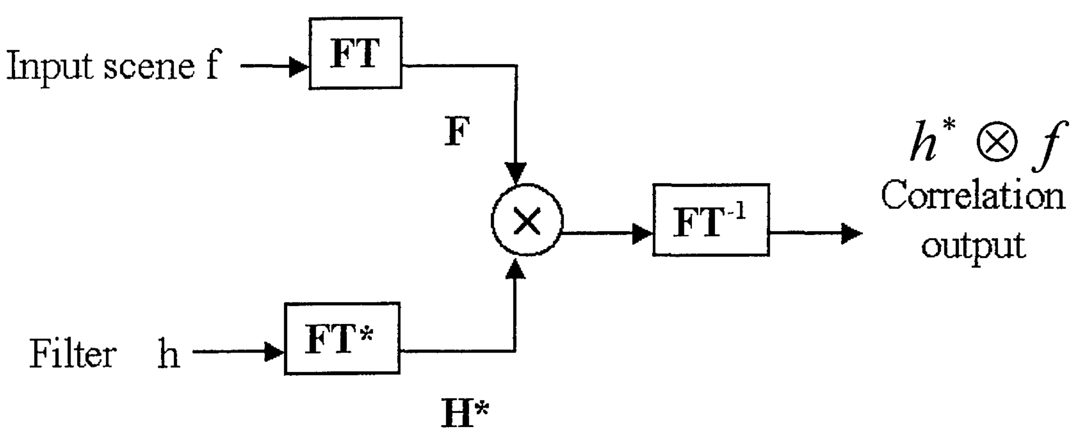

Fig. 3 Analog system diagram

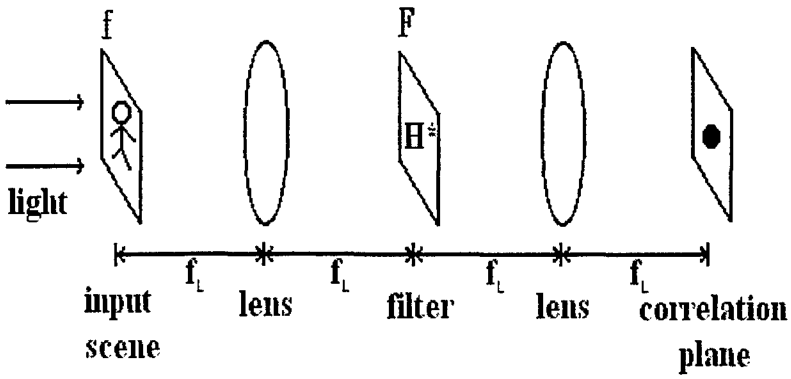

Fig. 4 An optical signal processor

Now we design the CEM filter. The basic idea of CEM filter is to constrain the central correlation amplitudes for training images and to minimize the average output correlation plane energy. Let us denote the training images by $f_i(x, y)$. Let $F_i(u, v)$ represent the Fourier transform of $f_i(x, y)$, and let $H^*(u, v)$ represent the filter function in the Fourier frequency domain. We first constrain the filter to satisfy the desired correlation response as below.

$$\iint F_i(u,v)H^*(u,v)dudv = c_i \qquad i = 1,2,\ldots,N, \tag{1}$$

where c_i is the pre specified constant, the subscript i refers to the i-th training image, and N is the number of training images. The CEM filter is designed to minimize the average correlation plane energy (which is related to the sharpness of the correlation peak) given by

$$E_{ave} = \frac{1}{N}\sum_{i=1}^{N} \iint |F_i(u,v)|^2 |H(u,v)|^2 dudv, \tag{2}$$

where Parsecal-Rayleigh's energy theory has been used to derive the above equation for the average correlation plane energy. To minimize E_{avg}, it is much convenient and powerful to use the vector/matrix notation. Then Eq. (1) can be rewritten as

$$F^T H^* = C, \tag{3}$$

where C is a column vector of size N with c_i as entries, H^* is a column vector with discrete spatial variables obtained by scanning the filter from left to right and from top to the bottom, F is a matrix with each column vector corresponding to the sampled Fourier transform of each training image. For convenience, we define a matrix A (which is average power spectrum

over all training images), whose elements are

$$A(u,v) = \frac{1}{N}\sum_{i=1}^{N}\left|F_i(u,v)\right|^2 . \tag{4}$$

Using vector notation, the E_{ave} in Eq. (2) can be rewritten as

$$E_{ave} = H^{+}AH, \tag{5}$$

where + denotes complex conjugate transpose and A is a diagonal matrix with its diagonal elements corresponding to the average power spectrum.

By using the Lagrange functional method, minimizing E_{ave} in Eq. (5) under the constraints in Eq. (3) leads to the following filter function in the frequency domain.

$$H^{*} = A^{-1}F^{*}\left[F^{T}A^{-1}F^{*}\right]^{-1}C, \tag{6}$$

where * refers to complex conjugate. Since A is a diagonal matrix, its inverse is trivial. The only non-trivial matrix inversion needed is that of $\left[F^{T}A^{-1}F^{*}\right]$, which is a N by N matrix.

Since the adjustment of Fourier plane correlator is hard to achieve. The joint transform correlator has been found to improve the drawback. The main advantages of JTC are that the reference image can be updated in real time, it does not require filter fabrication beforehand, and it avoids the precise the position of the filter otherwise required in Vanderlugt-type correlators. Fig. 5 shows the joint transform correlator.

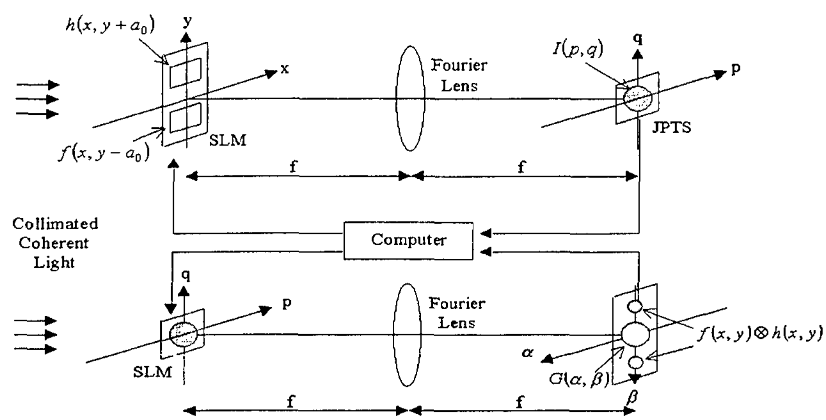

Fig. 5 The joint transform correlator.

Nevertheless, the JTC suffers from poor detection efficiency, particularly for multi-target and high-background noise environments. This disadvantage is primarily due to the existence of the zero-order spectra. The power spectrum subtraction technique can be used to remove the zero-order diffraction [18,19] and the output of JTC can be shown as [6,17]

$$g(\alpha,\beta)=h(x,y)\otimes f^{*}(x,y)*\delta(y-2a_0)+h^{*}(x,y)\otimes f(x,y)*\delta(y+2a_0), \tag{7}$$

where

$$h=\mathcal{F}^{-1}\{H\} \tag{8}$$

and $2a_0$ is the separation distance between the reference function *h* and the test image *f*.

3. Numerical Results

The numerical analysis of the proposed technique using CEM filter in JTC was investigated. For the reference and input objects, we used a 64×64-pixel image. The reference function has been designed on a Pentium III 450MHz computer. It took approximately 2 minutes of CPU time to run the computer program for the synthesis of the reference function. The JTC input is composed of two parts: the upper part is the input test scene, and the lower part is the synthesized reference image. Fig. 6 shows the input test scene of JTC. There are six input test images for correlation, 5 are for the legitimate user (each seal images has different rotation angle) and 1 is for similar but invalid user (the lower middle one). The magnitude of the reference image is depicted in Fig. 7. The joint transform correlation output is shown in Fig. 8(a). A three-dimensional profile of the output correlation is plotted in Fig. 8(b). Sharp correlation peaks corresponding to the authorized seal pattern are quite distinguishable and indicate the successful detection of the technique. The position measurement of the correlation can be computed as the location of the valid image. As anticipated, no strong correlation peak is observed for wrong image. Since the correlation output is symmetric, we can show only one cross correlation result. Fig. 9(a) illustrates the test for noise but valid patterns such as smeared and lined images. Fig. 9(b) reveals that the sharp correlation profile offers high detection efficiency.

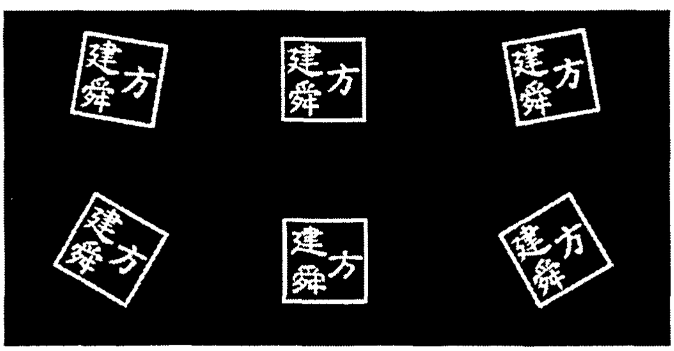

Fig. 6 An input test scene

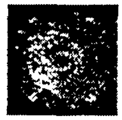

Fig. 7 The magnitude of the reference image

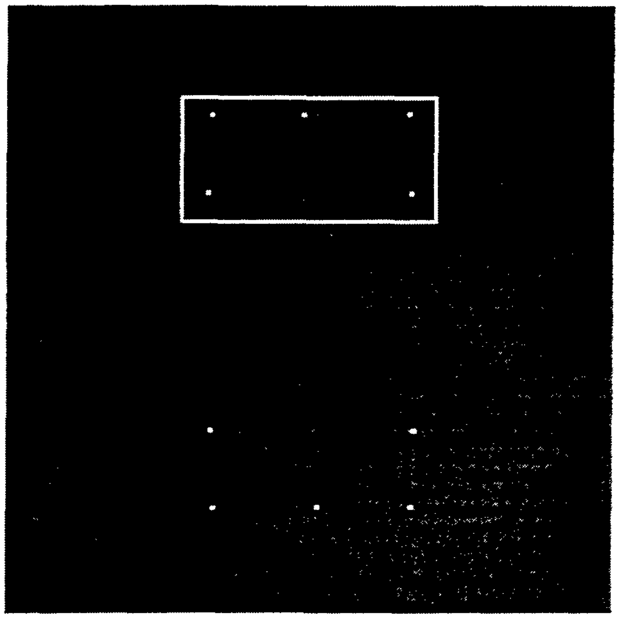

Fig. 8(a) The symmetric cross correlation output

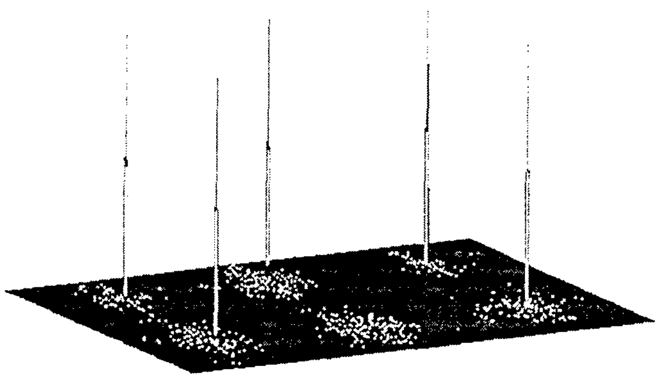

Fig. 8(b) The three-dimensional profile in the rectangular area

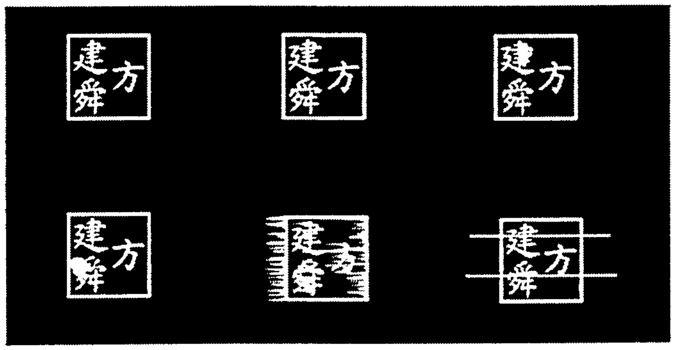

Fig. 9(a) An input test scene (smeared and lined images).

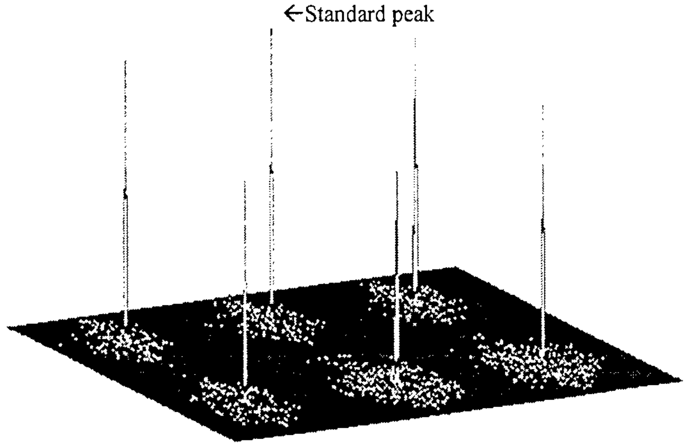

Fig. 9(b) The three-dimensional profile of cross correlation

4. Experimental Results

Now we are going to describe real tests. Satisfactory results have been obtained. An example of a Chinese money-withdrawing list, which includes a seal imprint, is shown in Fig. 10. A prototype Chinese seal recognition system is illustrated in Fig. 11. Fig. 12 shows the valid seal pattern. Recognition tests for rotational images are shown in Fig. 13(a) and Fig. 14(a), respectively. The corresponding output correlation profiles are shown in Fig. 13(b) and Fig. 14(b), respectively. Fig. 15(a) shows the invalid seal pattern, and the 3D profile is shown in Fig. 15(b). As anticipated, no strong and sharp correlation peak is observed for wrong image. Therefore, we can make a decision by giving a global threshold value of correlation peak, above which the image can be treated as a legitimate seal pattern and below which it is a illegitimate seal pattern.

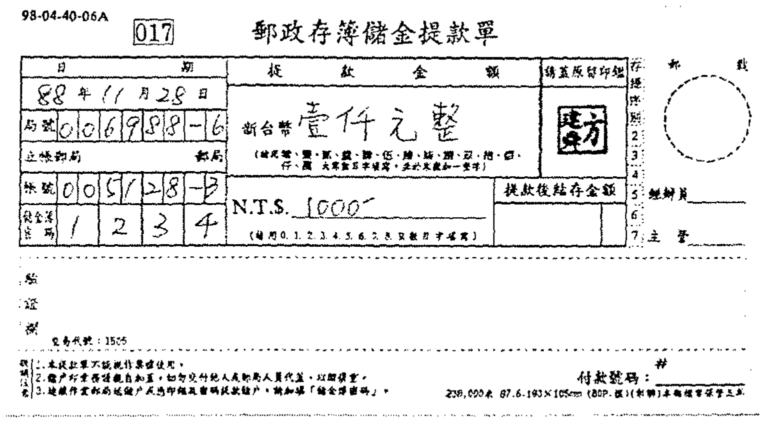

Fig. 10 A binary image of a Chinese money withdrawing list

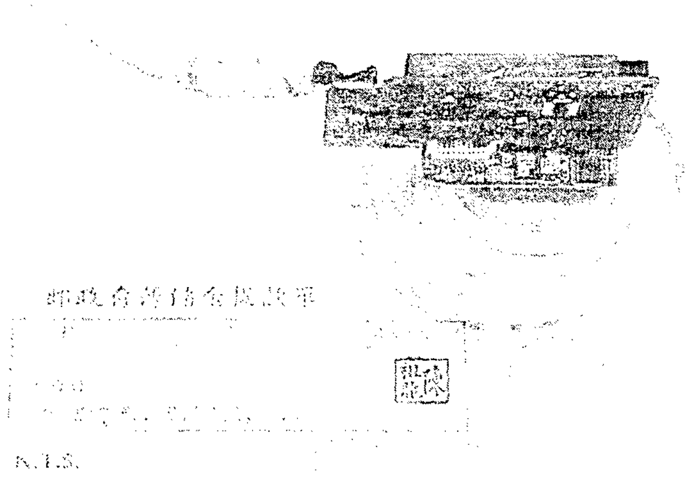

Fig. 11 A prototype Chinese seal recognition system

Fig. 12 The valid seal pattern

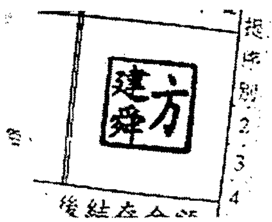

Fig. 13(a) A right-rotated correct image

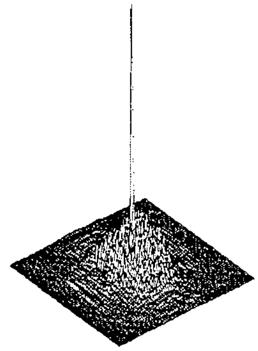

Fig. 13(b) The 3D Profile of cross correlation

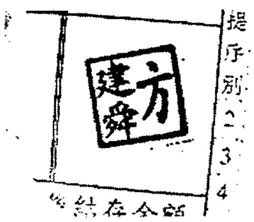

Fig. 14(a) A left-rotated correct image

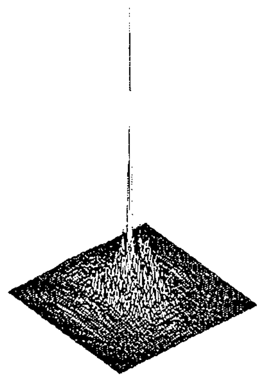

Fig. 14(b) The 3D Profile of cross correlation

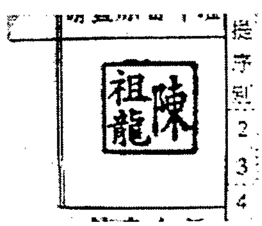

Fig. 15(a) An invalid seal pattern under test

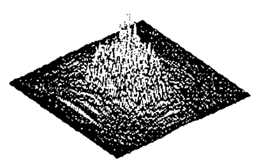

Fig. 15(b) The 3D Profile

5. Conclusion

We have describe a new scheme for Chinese seal pattern verification that combines the advantage of electronics and optics. The CEM filter designed for optical correlator has the desirable property of the sharp peak with low sidelobes levels in the output correlation plane. The major advantages of the system are alignment simplicity, rotation invariant capability, high discrimination capability, and suitability for hybrid optical signal processing. The test result indicates that the correlator produces reasonably good and impressive sharp correlation peak intensity at the valid seal location. With the choice of proper threshold in the output correlation, the proposed technique is shown to result in highly robust and discriminating detection.

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